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EVALUATION AND MEASUREMENT OF THE QUALITY OF THE ILLUMINATION SETUP IN A COLOR MANAGEMENT FACILITY

Vladimir KAMENOV[1] Valentin IVANOV[2]
[1]Department of Precision engineering and measurement instruments, Technical University - Sofia, Bulgaria
e-mail: vladokamenov@tu-sofia.bg
[2]Department of Precision engineering and measurement instruments, Technical University - Sofia, Bulgaria
e-mail: vgi@tu-sofia.bg

Abstract: In accordance to the authors' science project of evaluating the quality of office color printers, sponsored by the Bulgarian Science Research Fund, the following article will investigate a part of the "jungle" of color management and its implementation in color quality evaluation, namely – quality of the illumination of prepress rooms. If you are concerned about the accuracy and reproducibility of the colors you print, then you should also be with the quality of the environment in which they are seen and judged. This applies to both the color monitors and to ambient room lighting. The goal of this research is to examine the requirements of an illumination setup to be used for judging the color of printed material, and the various measurements that can be done to assess the setup performance.

Keywords: Color, Color management, Illumination

1. INTRODUCTION

Most computer users are aware of the importance of a calibrated display for accurate manipulation and editing of images, and many tools are available for such calibration. At the same time, most images are viewed under inadequate lighting conditions.

2. SETUP

2.1. Room description

Rooms designed for color work should be decorated with neutral colors. ISO 3664 recommends a neutral grey with a reflectance between 10% and 60%. Certain rooms are dedicated solely to the comparative viewing and assessment of prints. However, it is not uncommon to also find computer stations dedicated to image editing in these same rooms; in this case, we have the additional requirement that not only should the room colors be neutral, the room illumination level should be low. How low? ISO 3664 recommends a maximum of 64 lux, with a value of 32 lux or less. The room used for the measurements described in this paper has all walls painted with a light grey paint selected to approximate Munsell N8, with 80% nominal reflection. Here is the measured wall reflectance spectrum:

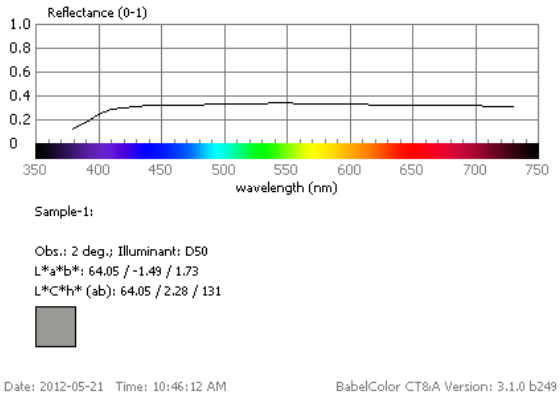

Figure 1 : The measured wall reflectance spectrum

At nearly 40%, the wall's reflection is bellow the recommended 60% from ISO 3664, but still way better than most working rooms; to be safe, we placed black cardboards on the wall near the measurement table.

One should take particular care to place sheets of black cardboard over any possible color contaminants, such as library shelves filled with colorful books about color, for example.

The laboratory should look like this:

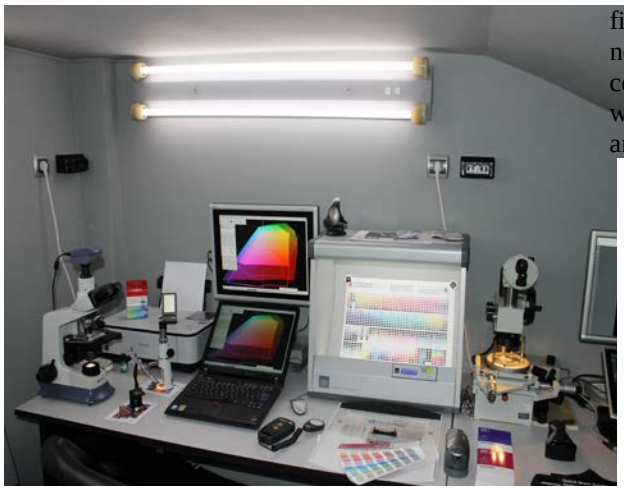

Figure 2: The laboratory

2.2. Illumination systems

We will investigate a variety of illumination systems: two fluorescent tubes designed for color rendering applications, one commercial light booth designed for direct viewing of printed material and monitor to print comparisons, and a CCFL bulb Dynaphos, specifically designed to reproduce daylight.
Our selection was based on the available products we could order for our laboratory, which may be quite different than others' setup. In any case, the methods and procedures shown apply to most setups.

Note: The measurements, presented here, may not be representative of all units manufactured under the same part number, as can be recognized by the fact that some light booth manufacturers will, on demand, try to match a replacement lamp to the batch used for original.

Here are detailed descriptions of each system:

1. Osram fluorescents, model "L36W/950" with correlated color temperature 5300K; color rendering index R_a = 98; ISO 3664 certified. Two 36W tubes mounted in a simple commercial fluorescent holder of the type shown in the picture below. The holder is painted in nearly neutral grey paint. You will note that the fixture has no diffuser between the tubes and the illumination zone (the viewing table). One of the consequences of using such a fixture is non-uniformity in the color temperature of the illumination because the light coming directly from the tube is different than the light reflected by the fixture; this is discussed further in this section. We nonetheless present results for this tube-fixture combination since it is ubiquitous in many workplaces. Approximate age of tubes is 0.5 years and they were used about 5 -10 hours.

Figure 3: Normlicht Color Communicator

2. Just Normlicht Color Communicator 1 Part no.91983 light booth. This booth uses two custom Just Normlicht fluorescent tubes (daylight 5000 proGraphic LL/SE15W.
Lighting technology fluorescent tubes fully meet the requirements of ISO 3664-2000: tightest tolerance of color temperature (+/- 200 K), exact color coordinates (tolerance +/ - 0,005), even spectral power distribution, maximum color rendering values Ra8 = 98, Ra215 = 95.6).
Light output can be adjusted using a continuously variable potentiometer. Approximate age of tubes is 3 months and they were used about 2-10 hours.

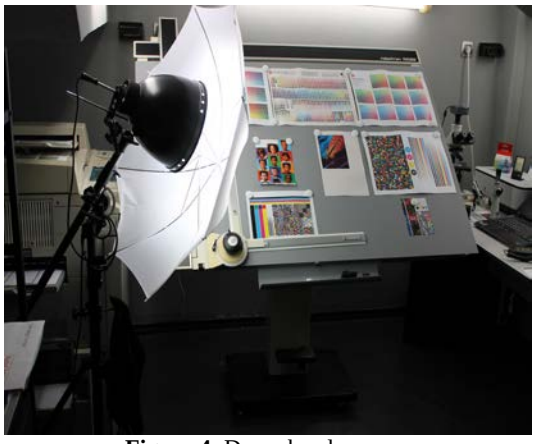

Figure 4: Dynaphos lamp

3. Dynaphos full spectrum energy saving lamp 35W (equivalent to 175W tungsten bulb), 5500K color temperature, E27 socket.
The lamp used for these measurements was mounted in a Dynaphos light kit for socket lamps with umbrella socket, angle adjustment, ceramic socket reflector 30 cm in diameter.
The lamp has been lit for less than 5 hours.

2.3. Instrumentation

All measurements made for this document were made using Eye-One Pro spectrometers manufactured by the Gretag Macbeth Company. The figures were either produced by, or are screenshots of the Spectral tools of the BabelColor software.

3. SPECTRUMS AND CCT

In this section, we look at the spectrum of each lamp and measure their Correlated Color Temperature (CCT). For the fluorescent tubes, we also measure the reflectance spectrum of the fixtures in which they are mounted.

3.1. Osram fluorescents

The black spectrum (Sample-1) in the upper section of Figure 1 shows the light output of the bare Osram tubes at a distance of approximately 74 cm, as measured in ambient mode with the Eye-One ambient diffuser. A black cardboard was placed between the tubes and the fixture to make sure we did not include the "color" of the fixture's grey diffuser in our measurement. The tube spectrum is expressed in units of absolute spectral irradiance density, in mw/nm/m2. The illuminance is 668 lux and the CCT is 5050 K, close to the tube nominal value of 5000 K. We notice peaks at 440, 490 550, and 620 nm which likely correspond to four of the seven phosphors used in manufacturing these patented tubes [5].

`The spectrum drawn in red (Sample-2) is the reflectance of the grey diffuser paint covering the fixture which holds the tubes; units are absolute and shown with a scale between zero and one. The third spectrum in the bottom of Figure 5 is obtained by multiplying the bare tube spectrum with the reflectance of the diffuser (Sample-1 x Sample-2); this is not the spectrum of the light actually reflected by the fixture, which is shown in Figure 3, but a mathematical derivation of the combination.

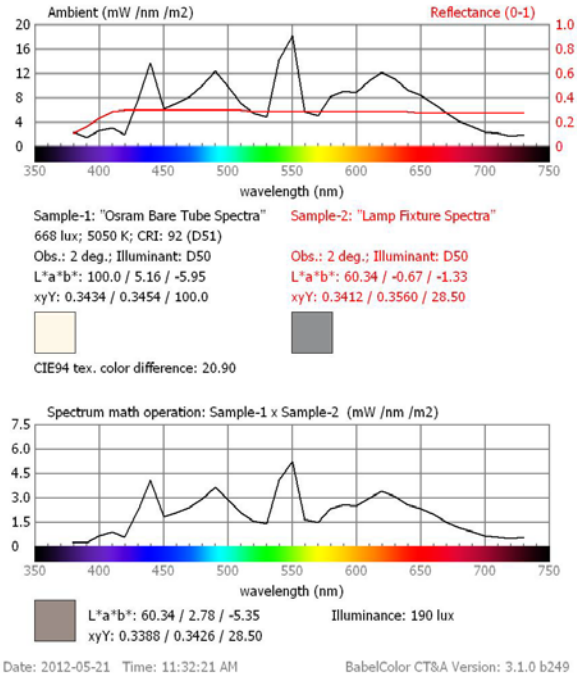
Ambient (mW /nm /m2)
Reflectance (0-1)
wavelength (nm)
Sample-1: "Osram Bare Tube Spectra"
668 lux; 5050 K; CRI: 92 (D51)
Obs.: 2 deg.; Illuminant: D50
L*a*b*: 100.0 / 5.16 / -5.95
xyY: 0.3434 / 0.3454 / 100.0
Sample-2: "Lamp Fixture Spectra"
Obs.: 2 deg.; Illuminant: D50
L*a*b*: 60.34 / -0.67 / -1.33
xyY: 0.3412 / 0.3560 / 28.50
CIE94 tex. color difference: 20.90
Spectrum math operation: Sample-1 x Sample-2 (mW /nm /m2)
wavelength (nm)
L*a*b*: 60.34 / 2.78 / -5.35
xyY: 0.3388 / 0.3426 / 28.50
Illuminance: 190 lux
Date: 2012-05-21 Time: 11:32:21 AM
BabelColor CT&A Version: 3.1.0 b249

Figure 5: Osram bare tubes (Sample -1) and fixture reflectance (Sample-2)

The color patches are computed relative to a D65 monitor, for the sRGB color space, which explains why the tube "white" (Sample-1), at 5050 K, is seen as slightly yellow. We can see that the diffuser (Sample-2) has a small bluish tint and the computed spectrum reflected by the diffuser (Sample-1 x Sample-2) an overall pink-orange tint. We also see a small increase in the blue portion of the (Sample-1 x Sample-2) spectrum; the first peak at 440 nm is higher than the 550 and 660 peaks whereas in Sample-1, the peaks are of equal height. These measurements simply show that the resulting color is a mix of the bare tube characteristics combined with the reflectance of the light fixture. The L*a*b* and xyY coordinates shown are computed for D50 and the 2 degrees Observer.

The upper part of Figure 6 shows another measurement of the bare-tube spectrum while the bottom part shows the same spectrum with an "ideal" spectrum, in fact the theoretical D-series spectrum, of the same CCT, 5057 K (rounded to the nearest 100 K. i.e. 5100 K, hence D51), and the same illuminance, 487 lux. You can notice how the phosphor peaks

detract from the smoother D51 shown in green. These peaks could likely affect the performance of the illumination system in terms of daylight simulation accuracy.

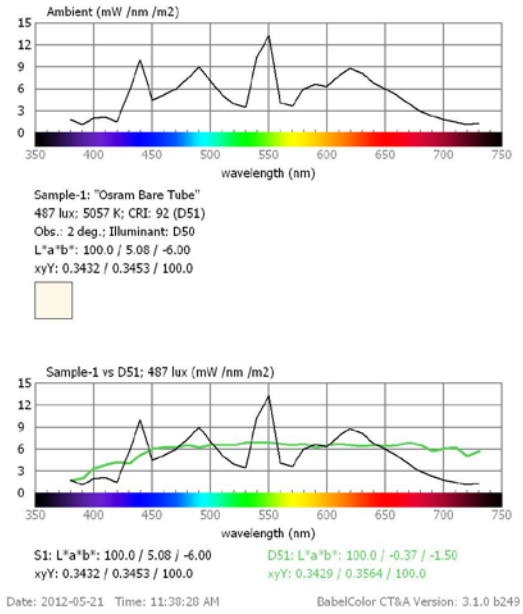
Ambient (mW /nm /m2)
wavelength (nm)
Sample-1: "Osram Bare Tube"
487 lux; 5057 K; CRI: 92 (D51)
Obs.: 2 deg.; Illuminant: D50
L*a*b*: 100.0 / 5.08 / -6.00
xyY: 0.3432 / 0.3453 / 100.0
Sample-1 vs D51; 487 lux (mW /nm /m2)
wavelength (nm)
S1: L*a*b*: 100.0 / 5.08 / -6.00
xyY: 0.3432 / 0.3453 / 100.0
D51: L*a*b*: 100.0 / -0.37 / -1.50
xyY: 0.3429 / 0.3564 / 100.0
Date: 2012-05-21 Time: 11:38:28 AM
BabelColor CT&A Version: 3.1.0 b249

Figure 6: Osram bare tubes (Sample-1) vs theoretical D51 spectrum (in green) of same illuminance

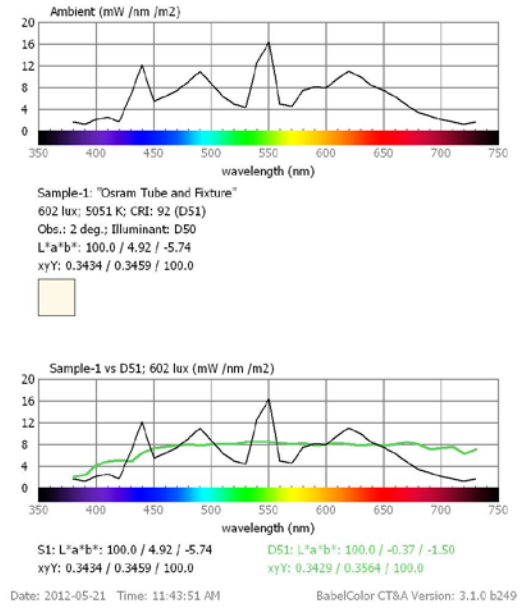
Ambient (mW /nm /m2)
wavelength (nm)
Sample-1: "Osram Tube and Fixture"
602 lux; 5051 K; CRI: 92 (D51)
Obs.: 2 deg.; Illuminant: D50
L*a*b*: 100.0 / 4.92 / -5.74
xyY: 0.3434 / 0.3459 / 100.0
Sample-1 vs D51; 602 lux (mW /nm /m2)
wavelength (nm)
S1: L*a*b*: 100.0 / 4.92 / -5.74
xyY: 0.3434 / 0.3459 / 100.0
D51: L*a*b*: 100.0 / -0.37 / -1.50
xyY: 0.3429 / 0.3564 / 100.0
Date: 2012-05-21 Time: 11:43:51 AM
BabelColor CT&A Version: 3.1.0 b249

Figure 7: Osram tubes with fixture (Sample-1) vs theoretical D51 spectrum (in green) of same illuminance

The black spectrum (Sample-1) in the upper section of Figure 7 shows the light output of the Osram tubes combined with the effect of the tubes' fixture at a distance of approximately 102 cm, as measured in ambient mode with the Eye-One ambient diffuser. These spectrums shapes (not their absolute levels since the measuring distance is different) should be compared with the ones of Figure 2. The CCT is slightly lower, 5051 K compared to 5057 K, due to the fixture's bluish tint. The phosphor peak at 440 nm is slightly higher than the 550 nm and 660 nm peaks, corresponding to what was predicted in the computed (Sample-1 x Sample-2) spectrum of Figure 2. The bottom section of Figure 3 compares Sample-1 with a theoretical ("ideal") spectrum of the same CCT and illuminance.

You should not be too concerned by the dip of the measured spectrum at wavelengths higher than 670 nm; the eye is not very sensitive in this region and the effect of the difference is minimal. [5]

3.2. Dynaphos 5500K lamp

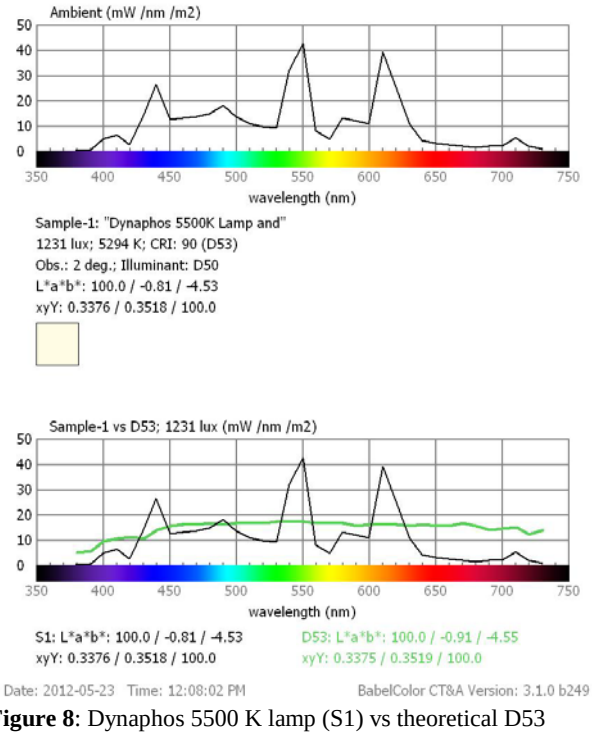
Ambient (mW /nm /m2)
wavelength (nm)
Sample-1: "Dynaphos 5500K Lamp and"
1231 lux; 5294 K; CRI: 90 (D53)
Obs.: 2 deg.; Illuminant: D50
L*a*b*: 100.0 / -0.81 / -4.53
xyY: 0.3376 / 0.3518 / 100.0
Sample-1 vs D53; 1231 lux (mW /nm /m2)
wavelength (nm)
S1: L*a*b*: 100.0 / -0.81 / -4.53
xyY: 0.3376 / 0.3518 / 100.0
D53: L*a*b*: 100.0 / -0.91 / -4.55
xyY: 0.3375 / 0.3519 / 100.0
Date: 2012-05-23 Time: 12:08:02 PM
BabelColor CT&A Version: 3.1.0 b249

Figure 8: Dynaphos 5500 K lamp (S1) vs theoretical D53 spectrum (in green) of same illuminance

The spectrum (S1) in the upper section of Figure 8 shows a measurement of the light output of the Dynaphos lamp in its fixture at a distance of about 1 m, on axis. Figure 4 should be compared with Figure 3.

The measured illuminance is 1231 lux and the CCT is 5294K. The green spectrum in the bottom section of the figure is the spectrum of an ideal D53 Illuminant. The match is close, with the exception of the peaks seen with fluorescent bulbs.

In the figure, D53 was automatically selected as the "ideal" illuminant because it is the closest rounded illuminant to the 5294K CCT. However, we could also have imposed D50 as the "Reference Illuminant" for comparison purposes.

3.3. Just Normlicht Color Communicator 1 light booth

Figure 9: Just Normlicht light

The spectrum in the upper section of Figure 10 shows the light output of the Just Normlicht light booth as measured in the center of the booth vertical viewing plane. We adjusted the illuminance to a value around 2000 lux, corresponding to the "P1-Critical comparison" conditions called for in ISO 3664 (discussed in the next section); we did not verify if the color temperature varied for lower illuminance levels. The measured illuminance is 2115 lux and the CCT is 4854K, significantly warmer than the Dynaphos lamp, but similar to the Osram tubes. This spectrum is reproduced in black in the bottom section of Figure 6 and the green spectrum corresponds to a theoretical D49 illuminant of the same illuminance. We notice two peaks on the tubes spectrum, at 440 and 550 nm, which correspond to the same phosphors in the other tubes, and we see much smaller ones at 480 and 580 nm. There is also a fall-off in the red spectral region starting at 630 nm, but not as dramatic as with the Osram and Dynaphos tubes.

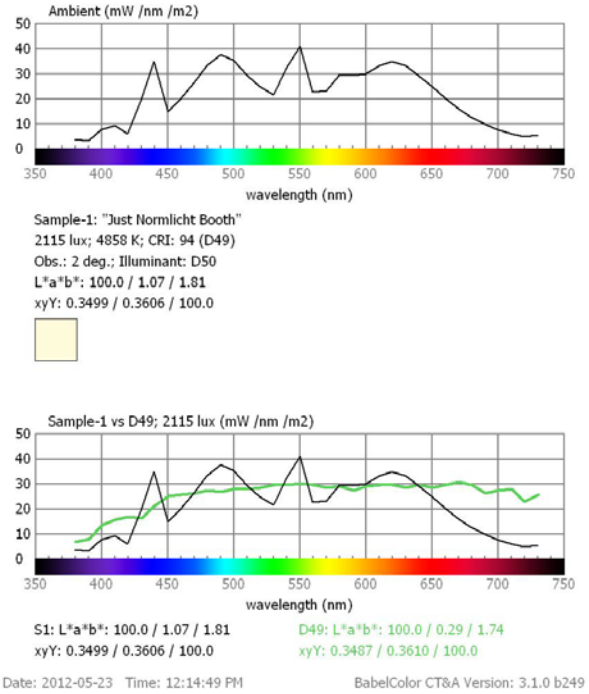

Figure 10: Just Normlicht Color Communicator 1 light booth spectrum (Sample-1) vs theoretical D49 spectrum (in green) of same illuminance

4. ISO 3664 MEASUREMENTS

The ISO 3664 standard —Viewing conditions - Graphic Technology and Photography— is mostly a collection of other standards and accepted procedures to which it makes reference, and from which it selects particular conditions in regards to its specific target audience. The parameters defined in the standard were measured for the Osram fluorescent fixtures and Just Normlicht light box. We did not measure the uniformity of the Dynaphos lamp since this is a pointless exercise for a point light! However, we did measure the other characteristics of this lamp. [3]

4.1. Osram fluorescent lamps

Figure 11: Osram bare tubes ISO 3664 test results (P2 viewing conditions). Tube-to-table distance: 74 cm.

Figure 11 shows the measured characteristics of the bare Osram tubes relative to the P2 viewing condition; a black cardboard was inserted between the tubes and the fixture in order to measure the output from the tubes only. The tube-to-table distance was 74 cm and the zone that met the 75% uniformity criteria, corresponding to the Brightness uniformity data, was measured to be about 74 cm x 52 cm. As shown in Figure 7, because the measuring zone was defined to meet the uniformity test, this test has a PASS rating.

The Brightness, the Meas. Temp. (CCT), the Chromaticity, the CRI with individual Special indices, and the MI/Quality Grade, corresponding to the central position, as selected in the Brightness uniformity group, are also shown. This information is available for the five positions shown in the Brightness uniformity group.

The chromaticity test, measured in u'v' coordinates, has failed. This is another way of indicating that the CCT is slightly high; however, all other results for this position have a PASS rating.

The eight Special indices from which the CRI is determined are shown; to meet the requirement, they should all be equal or superior to 80. In addition, the CRI, which is the average of these eight values, should also be higher than 90%. This goal is met.

The "C" Quality Grade is adequate without being great. The MI value, as well as the individual differences for the five metameric pairs, was obtained from an exported measurement report, using the "Export to file…" button. In this case, the MI value for the center position is 0,93, near the bottom limit of the C grade zone defined in Table 2 (Grade "C" is valid up to an MI of 1).

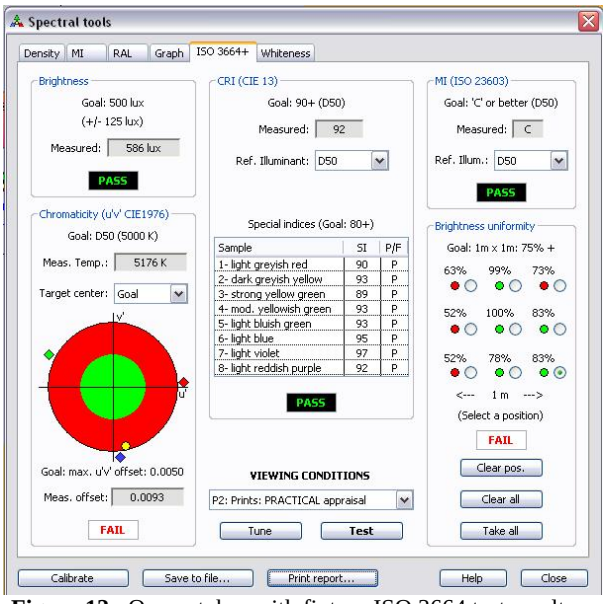

Figure 12: Osram tubes with fixture ISO 3664 test results (P2 viewing conditions). Tube-to-table distance: 102 cm.

Figure 12 shows the measured characteristics of the Osram tubes mounted in their fixture relative to the P2 viewing condition. The tube-to-table distance was 102 cm and the zone that met the 75% uniformity criteria, corresponding to the Brightness uniformity data, was measured to be about 74 cm x 64 cm. The figure shows the results corresponding to the central position.

By comparing the data of Figure 7 and 8, and the exported report data of each test, we see a few effects of the diffuser:

a. The diffuser increases the color temperature by 110 K. In fact, with the fixture, we measure a CCT of 5176K over the zone which covers our 75% brightness uniformity criteria, with the maximum roughly in the zone center. This indicates that our fixture is not a perfectly uniform diffuser.
b. The chromaticity offset is increased. This goes in pair with the increased CCT due to the bluish tint of the fixture diffuser.
c. The CRI and MI are essentially the same.

4.2. Just Normlicht Color Communicator 1 light booth

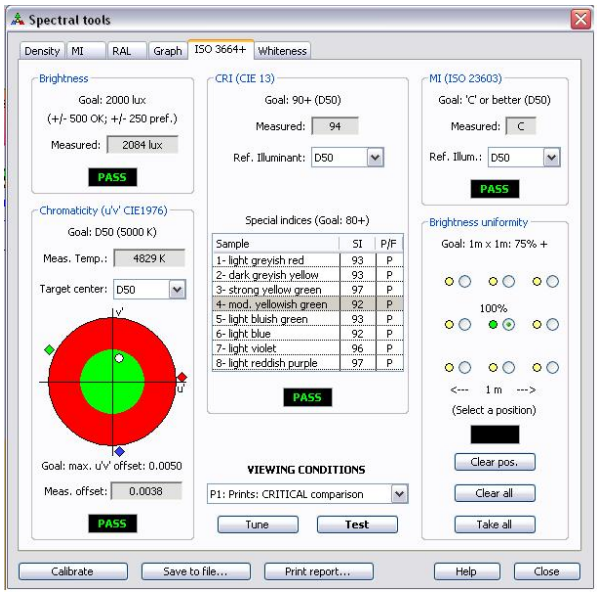

Figure 13: Just Normlicht light booth ISO 3664 test results (P1 viewing conditions)

Figure13 shows the measured characteristics of the Just Normlicht light booth set for the P1 viewing condition. Because of its particular illumination geometry, a horizontal top light illuminating a vertical viewing plane, it is impossible to achieve the degree of uniformity required by ISO 3664 and we only took our measurements in the center of the viewing surface for this viewing condition.

The CRI and Quality Grade are on the limit but still good; the MI from the exported report, is 0,93, very similar to the values obtained with the Osram tubes. The 4829 K color temperature (and chromaticity) is on the cool side (more orange).

4.3. Dynaphos lamp

Figure 14 shows the measured characteristics of the Dynaphos lamp set for the P1 viewing condition. We adjusted the distance at which the measurement was taken, about 56 cm, to match the P1 brightness requirement. Because this is a single lamp bulb, it is impossible to achieve the degree of uniformity required by ISO 3664 and we only measured the brightness in the beam center; the fall-off is quite rapid as soon as you go off-center.

The results are not remarkable, with a CRI of 91 and a "E" Quality Grade, which failed to even meet the goal of at least C. The individual color differences (CIELAB, 10 deg. Observer) for the five CIE S 012 metamers are:

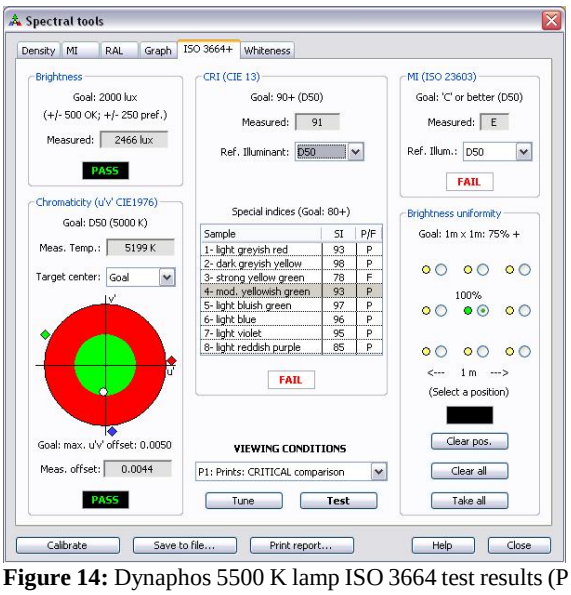

Figure 14: Dynaphos 5500 K lamp ISO 3664 test results (P1 viewing conditions)

CIELAB and MI data for each position:

Position: Center

Metamer #	CIELAB
metamer-1	0.71
metamer-2	4.28

metamer-3 2.63
metamer-4 2.43
metamer-5 1.56
Average (MI): 2.32
Note:
Munsell equivalent values are approximate and correspond to patches viewed under Illuminant C.

5. CONCLUSION

You should not expect a "This is the best light source you should buy!" type of conclusion here. As the title indicates, this is a "How to…" paper and not a product review.
However, looking strictly in terms of simulating D50, the Just Normlicht viewing booth is certainly the most accurate lamp we have tested. But an illumination setup is more than just matching a light source; how about having a large uniform illumination zone at a prescribed illuminance level? This is much more difficult to achieve with Dynaphos spot lamps than with fluorescent tubes.
As we have seen, the Osram tubes have similar performance in terms of daylight simulation. In any case, while these tubes strive to give you an "ideal" D50, they exhibit slightly different color temperatures, a difference which is compounded, again, by the respective fixtures we had available. Is it better to select a slightly cooler or hotter color temperature? This is a matter of personal taste, compatibility with your supplier or customer, and cost.
The facts that, in all fluorescent lights, individual phosphors are combined to achieve a given spectrum, and that these phosphors are characterized by individual peaks, can only lead to different metameric properties for these tubes. When we compared printed images with both setups, the visual assessments did differ; some colors better matched the colors seen on our monitor under one illumination system than the other.
You can save money by buying individual fluorescent tubes, but we saw that a fixture can affect the light characteristics. For instance, if the light from the bare tube and the reflected light from the fixture are spectrally different, it is likely that the color temperature of the light in the viewing plane will be non-uniform, unless the fixture incorporates a diffuser which thoroughly mixes the two spectrums (or that the fixture is far away). Knowing how to measure the effect of a fixture is a step in the right direction.
If money is no object, buying a complete light booth from a single supplier is another solution. There again, there are differences between manufacturers, and differences between models from a given manufacturer. You can see endless debates in web forums on the respective advantage of products from one company relative to another company's products. If you look at each manufacturer's specification, they all meet the same generic requirements of CIE 13 and CIE 51/CIE S 012. We have seen that the difference is in the details, and these details can explain many of the subjective comments that can be read. Meeting a standard only means that a product is within a defined performance range, but there is no formal statement that images will look exactly the same when viewed under illumination systems of different manufacturers, even though this may be thought so by the unaware user.
Assessing a system performance on CRI alone is useless. Combining the CRI with the chromaticity, the color temperature and, particularly, the Quality Grade, as determined with CIE S 012 (or CIE 51), is a much better procedure. These parameters are the basis of ISO 3664; while meeting this standard's minimal requirements is sufficient for most professional tasks, understanding how they interact and seeking optimum values will help you improve the reproducibility and quality of your work.

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